Conf - 910615--1

ANL/CP--73018

DE91 012477

11

Helium Processing for Deuterium/Helium Burns in ITER's Physics Phase

P. A. Finn and D. K. Sze

Chemical Technology Division/Fusion Power Program

Argonne National Laboratory

9700 South Cass Avenue

Argonne, IL, 60439, U.S.A.

DISCLAIMER

The submitted manuscript has been authored by a contractor of the U. S. Government under contract No. W-31-109-ENG-38. Accordingly, the U. S. Government retains a nonexclusive, royalty-free license to publish or reproduce the published form of this contribution, or allow others to do so, for U. S. Government purposes.

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

Work supported by the U.S. Department of Energy,
Office of Fusion Energy, under Contract W-31-109-Eng-38.

MASTER
DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

Helium Processing for Deuterium/Helium Burns in ITER's Physics Phase

P. A. Finn and D. K. Sze

Chemical Technology Division/Fusion Power Program

Argonne National Laboratory

9700 South Cass Avenue

Argonne, IL, 60439, U.S.A.

Abstract

The requirements for vacuum pumping and fuel processing for deuterium/helium ($D/{}^3\text{He}$) burns in the physics operating phase for the International Thermonuclear Experimental Reactor (ITER) were assessed. These burns are expected to have low fusion power (100 MW), short burn times (≤ 30 s), limited operation (2000 shots), and a fractional burn $\sim 0.3\%$. For the physics phase, the fuel processing system will include several units to separate deuterium and helium (activated charcoal bed, SAES getter and a Pd/Ag diffuser), as well as an isotopic separation system to separate ${}^3\text{He}$ and ${}^4\text{He}$. The needed vacuum system's cryosorption surface area may be as large as 10 m^2 if the burn time is ~ 200 s, the fractional burn is $< 0.3\%$, or the fusion power is > 100 MW.

1. Introduction

During the physics operating phase of ITER, both deuterium/tritium (D/T) and deuterium/helium (D/³He) burns are planned. The products of these two fusion reactions are given in Eq. 1 and 2, where n is a neutron and p is a proton.

If both reactions have a fractional burn of 3%, then in D/³He burns, 67 mol % of the pumped gas is helium, whereas in D/T burns, only 3 mol % of the pumped gas is helium. This corresponds to a helium mol ratio of 32 when one compares D/³He burns to D/T burns (Table 1). The mol ratio increases to 320 for a fractional burn of 0.3%. In addition, the fuel processing requirements for a D/³He burn are to separate helium from deuterium, purify the deuterium, purify the helium, and separate ⁴He from ³He. Therefore, we assessed the vacuum and fuel processing needs for D/³He burns to determine the type of systems required.

2. Vacuum System for Helium Pumping for a D/³He Burn

For D/³He burns, cryosorption pumps would be used and would be designed to pump hydrogen and helium species independently. Species separation is important since the measured helium capacity of a cryosorption pump under sustained pumping is $\sim 2260 \text{ Pa}\cdot\text{m}^3/\text{m}^2$ [1-2] (324 mol/m²) if only helium is pumped and $\sim 526 \text{ Pa}\cdot\text{m}^3/\text{m}^2$ [3] (64 mol/m²) if both helium and deuterium are coadsorbed.

A further consideration for pumps is the ability to regenerate deuterium and helium separately. Anderson, et al. [3] has shown that cryosorption pumps can achieve 75-90% separation during pump regeneration if the condensing cold panel is kept at 4 K while pumping the helium away at pressures $< 10^{-2}$ Pa. A 99% separation is essential for ITER D/³He burns in order to process separate helium and deuterium streams.

The parameters for a base D/³He burn are listed in Table 2. The assumed fractional burn is $\sim 0.3\%$. At this fractional burn, the ³He throughput would be 16 mmol/s, corresponding to a gas load of $38 \text{ Pa}\cdot\text{m}^3/\text{s}$ (STP). The D₂ throughput would be 8 mmol/s, corresponding to a gas load of $19 \text{ Pa}\cdot\text{m}^3/\text{s}$.

A helium pumping speed of $384 \text{ m}^3/\text{s}$ (Table 3), and a helium gas load of $38 \text{ Pa}\cdot\text{m}^3/\text{s}$, would result in a total helium partial pressure of ~ 0.1 Pa, which is two orders of magnitude larger than the helium partial

pressure required for D/T burns. This higher partial pressure would be acceptable for a D/ ^3He burn if the ^4He partial pressure could be maintained at 10^{-3} Pa. (For a fractional burn of 0.3%, the ^4He partial pressure would be initially $\sim 10^{-3}$ Pa but would increase to 10^{-2} Pa after 10 shots, each 30 s long, if the helium was not processed to remove ^4He .) Thus, a helium pumping speed of $384 \text{ m}^3/\text{s}$ appears adequate if one provides a method to separate ^3He and ^4He .

The needed sorption surface area for helium pumping was also assessed. For D/ ^3He , 1 m^2 of cryosorption surface area would have to collect $\sim 7.5 \text{ mol}$ of helium in 1 hour of continuous burn with a sequence of multiple D/ ^3He 30 s burn shots done sequentially. In comparison, 1 m^2 of surface area would only collect 2 mol of helium in 1 hour for two D/T burn shots of 1000 MW, each 2000 s.

The effect of three parameters, longer burn times ($\sim 200 \text{ s}$), lower fractional burns ($< 0.3\%$) and higher fusion power, (1000 MW), on D/ ^3He pumping requirements was also examined. If the burn time is increased from 30 to 200 s, the helium partial pressure is unaffected; however, the required sorption surface area increases a factor of seven, (7 m^2) if the regeneration time is unchanged. If the fractional burn is 0.1%, the helium gas load is $114 \text{ Pa}\cdot\text{m}^3/\text{s}$, and the needed sorption surface area increases by a factor of three, i.e., 3 m^2 . If the fractional burn is 0.03%, the helium gas load is $380 \text{ Pa}\cdot\text{m}^3/\text{s}$ and the required sorption surface area is ten times larger (10 m^2). Last, if the fusion power is

increased to 1000 MW, the helium gas load is $380 \text{ Pa}\cdot\text{m}^3/\text{s}$ and the required sorption surface is 10 m^2 . Thus, the required cryosorption surface area is highly dependent on the type of D/ ^3He burn sequence assumed. (Here we have assumed a minimum regeneration time of 1 h to minimize valve wear.)

3. Fuel System Needs to Handle D/ ^3He Burns

Helium processing units are needed to separate entrained hydrogen species from helium after vacuum pump regeneration, and to isotopically separate ^3He and ^4He . The deuterium gas load (8 mmol/s) can be handled by a standard D/T fuel cleanup system, followed by a hydrogen cryogenic distillation unit. The units in the fuel processing system and their interconnections are shown in Fig. 1.

The regenerated helium from a cryosorption pump would pass through an activated charcoal bed at liquid nitrogen temperature to remove hydrogen species and other impurities. Then, this stream would pass through a SAES 707 getter bed to remove any entrained deuterium before the helium is passed to a helium cryogenic distillation unit. Deuterium, which is regenerated from the activated charcoal bed and the SAES getter, would be processed in a standard D/T fuel cleanup system, to remove water and hydrocarbon impurities. The regenerated deuterium from the cryosorption pump would also pass through the D/T fuel cleanup system. The combined

stream would pass through a hydrogen cryogenic distillation unit. To recover ^3He in the output from the protium column of the hydrogen distillation unit, the output stream would pass to a palladium/silver diffuser. The protium would diffuse through the diffuser and be discarded as waste. The ^3He would be recycled to the activated charcoal bed.

A helium cryogenic distillation unit is not standard processing equipment. Therefore, earlier cryogenic distillation units[4-8] were examined to define the requirements of this unit. The production capabilities of these earlier units are summarized in Table 4. The maximum production capacity was that achieved by Tominaga[8], who had < 10 ppm ^4He in the ^3He product. A seven-fold scale-up of Tominaga's system to process 16 mmol/s of helium should be adequate for the needs of ITER's physics phase.

4. Conclusions

D/ ^3He burns are expected during the physics phase of ITER, burns of low power (100 MW), limited duration (≤ 30 s), low fractional burn ($\sim 0.3\%$) and limited operation (2000 shots). Therefore, the needed helium vacuum system and fuel processing system were assessed.

A helium pumping speed of 384 m^3/s with cryosorption pumps should be adequate. A more critical issue is the required helium sorption surface area under sustained pumping. The limit is $2660 \text{ Pa}\cdot\text{m}^3/\text{m}^2$. For D/ ^3He burns with burn fractions $< 0.3\%$, burn times ≥ 200 s, and/or fusion power

of 1000 MW, a cryosorption surface area of 10 m^2 may be required. Even the design of the cryosorption pump needs attention since current pumps[3] can only achieve 75-90% separation of deuterium and helium species, which could increase cryosorption surface area needs an additional factor of 4. Thus, the ITER team must define the burn scenario for $\text{D}/^3\text{He}$ burns so designers can specify the required surface area for ITER's vacuum system.

The ITER fuel processing system for $\text{D}/^3\text{He}$ burns will have to process hydrogen and helium species separately after they are regenerated from the cryosorption pumps. Six processing units are needed, an activated charcoal bed, a SAES getter bed, a palladium/silver diffuser, and a helium cryogenic distillation unit, as well as a standard D/T fuel cleanup unit and a cryogenic hydrogen distillation unit.

References

- [1] D. W. Sedgley, A. G. Tobin, T. H. Batzer, and W. R. Call, Cryopumping for fusion reactors, Nucl. Eng. Des./Fus. 4 (1987) 149-163.
- [2] J. L. Anderson, D. O. Coffin, and C. R. Walthers, Vacuum applications for the tritium systems test assembly, J. Vac. Sci. Technol. A1 (1983) 849-855.
- [3] J. L. Anderson, E. M. Jenkins, and C. R. Walthers, Tritium handling experience in vacuum systems at TSTA, Vacuum, 41, (1990) 1983-1987.
- [4] W. R. Abel, A. C. Anderson, W. C. Black, and J.C. Wheatley, Thermal and magnetic properties of liquid ^3He at low pressure and at very low temperatures, Physics, 1 (1965) 337-387.
- [5] T. Hata, mentioned in reference 8 as a private communication.
- [6] W. R. Wilkes, $^3\text{He}/^4\text{He}$ distillation apparatus, Mound Laboratory report, MLM-2005 (1973).
- [7] R. H. Sherman, The separation of ^3He from $^3\text{He}/^4\text{He}$ mixtures, Proc. of LT10, Moscow, (1968) pp. 188-191.
- [8] A. Tominaga, S. Kawano, Y. Narahara, Rapid purification of ^3He , J. Phys. D: Appl. Phys., 22 (1989) 1020-1024.

Table 1. Comparison of D/³He and D/T Throughputs

Fusion Reaction	He mol%	DT/D ₂ mol%	Fusion Power			
			1000 MW		100 MW	
			He mol/s	DT/D ₂ (H) mol/s	He mol/s	DT/D ₂ (H) mol/s
3% Fractional Burn						
D/ ³ He	67	33	1.6(-2)	8(-3)	1.6(-3)	8(-4)
D/T	3	97	5(-4)	1.6(-2)	5(-5)	1.6(-3)
Ratio He(D/ ³ He):He(D/T)			3.2(1)		3.2(1)	
0.3% Fractional Burn						
D/ ³ He	67	33	1.6(-1)	8(-2)	1.6(-2)	8(-3)
D/T	0.3	99.7	5(-4)	1.6(-1)	5(-5)	1.6(-2)
Ratio He(D/ ³ He):He(D/T)			3.2(2)		3.2(2)	

Table 2. Parameters for Base D/³He Burn

Parameter	Value
Fusion Power,MW	100
Fractional Burn, %	0.3
Burn Time,s	30
Dwell Time,s	200
Number of Shots	2000
Total Burntime,h/y	17

Table 3. Parameters for ITER's Vacuum System

Parameter	Value
Helium Pump Speed, m^3/s	100
Helium Duct Speed, m^3/s	93
Deuterium Pump Speed, m^3/s	190
Deuterium Duct Speed, m^3/s	93
Number of Ducts	8
Total Helium Speed, m^3/s	384
Total Deuterium Speed, m^3/s	496
Helium Partial Pressure, Pa	~ 0.001
Deuterium Partial Pressure, Pa	~ 0.1
Helium Pump Capacity, m^2	1-10
Regeneration Time, h	1

Table 4. Comparison of Distillation Units to Separate ^3He and ^4He

Description Reference	^4He Source %	Prod. ppm	Condenser Temp. K	Heater mW	Product mmol/s
Packed Column					
Abel[4]	$< 10^{-3}$	1.8	0.6	2	0.043
Hata[5]	5	100	1.1	3	0.020
Wilkes[6]	93	500	1.6	40	0.042
Packless Column					
Sherman[7]	3	3	2.2	60	0.069
Tominaga[8]	4.5	< 10	1.3	100	0.230

Figure 1. Processing System for D/He-3 Burns